Executive Summary

This Feasibility Study (FS) presents an evaluation of remedial alternatives for mitigating soil and groundwater contamination at Environmental Restoration Program (ERP) Site OT-17 (Site 17). Site 17 is located in the southeastern portion of Beale Air Force Base (AFB or Base) near Marysville, California. Figure ES-1 shows the location of Beale AFB, and Figure ES-2 shows the location of Site 17. (All figures are located at the end of each section.)

The FS is one of several steps that comprise the Comprehensive Environmental Restoration, Compensation, and Liability Act (CERCLA) process. Although Beale AFB is not on the National Priorities List, the Air Force implements the ERP in conformance with CERCLA. The content of this document follows the U.S. Environmental Protection Agency's (EPA) *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA, 1988).

The FS develops and evaluates remedial alternatives for mitigating contaminants of concern (COC) that exist in soil and groundwater within the Site 17 investigation area. The evaluation of alternatives presented in this FS will be used to support a Proposed Plan and Record of Decision in selection of the final remedial actions to be implemented at the site. The FS uses the site conceptual model, which was generated using information gathered during the remedial investigation (RI), to develop cleanup levels and evaluate remedial alternatives.

To facilitate development and evaluation of remedial alternatives in this FS, Site 17 subsurface contamination has been divided into three specific areas as follows (see Figure ES-2):

Area A – Primary Source Area: The contaminated area currently being contained and managed through an interim remedial action (IRA).

Area B – Secondary Source Area: A secondary contaminant source area of up to 2 acres immediately south of Area A. Up to 0.4 acre of this area is suspected to contain free-phase chlorinated solvents in the subsurface.

Area C – Dissolved Plume: The dissolved groundwater contaminant plume extending approximately 2,500 feet south of Area A and covering approximately 60 acres. Delineation of Area C is defined by groundwater contaminant concentrations that exceed cleanup levels.

Pursuant to CERCLA guidance (EPA, 1988), the remedial alternatives investigated in this FS are evaluated according to their ability to meet the following seven evaluation criteria:

1. Overall protection of human health and the environment
2. Compliance with applicable or relevant and appropriate requirements (ARAR)
3. Long-term effectiveness and permanence of the remedial action to minimize risks
4. Reduction of toxicity, mobility, and volume through treatment
5. Technical viability, reliability, and implementability
6. Compliance with regulatory requirements for any likely approvals, permits, and licenses
7. Costs of implementing the technology

Alternatives are evaluated against two additional criteria, state acceptance and community acceptance, after regulatory and public comment on the FS and the Proposed Plan.

Another criterion that will be used for this evaluation is the net environmental benefit analysis (NEBA). The NEBA is a process for comparing the benefits and costs associated with alternative remedial actions that affect the environment. The goal of a NEBA is to rank these alternatives in terms of the net benefits realized from their implementation. A NEBA was first used by EPA and the National Oceanic and Atmospheric Administration. It consists of a set of techniques and tools for comparing the benefits of alternative land uses and/or remedial actions that affect the environment.

Site Characterization and Contaminant Distribution

Site 17 occupies a low, gently sloping grassland of approximately 500 acres adjacent to Best Slough. Site 17 is located within an area designated as a "riparian habitat preservation area" in Beale AFB's *Integrated Natural Resources Management Plan* (U.S. Army Corps of Engineers, 1999). A habitat preservation area is designated to protect unique, rare, and otherwise important habitats. The important habitats within Site 17 include riparian habitat and areas of forest, scrub, and marsh habitat along the waterways.

Best Slough flows along the north side of the site, bends in a southerly direction, and continues to flow along the west side of the site. Dry Creek flows to the south along the east side of the site. The streams are hydraulically connected to the groundwater system. During the summer months, the groundwater generally flows into the streams. In the winter months, during storm episodes, the streams recharge the groundwater. Parks Lake, a relatively small and shallow lake, is located in the center of the southern area of Site 17, between Best Slough and Dry Creek (see Figure ES-2). The site is fenced but accessible via a network of dirt roads.

An IRA was implemented in 2001 to control the primary sources of contamination at Site 17. The primary feature of the IRA was the construction of a slurry wall around the source area to prevent further spread of contaminants (see Figure ES-2).

Further information about the location or physical features of Site 17 can be found in the Final Site 17 RI Report (CH2M HILL, 2004a).

Geology

The geology at Site 17 is characterized by an approximate 35-foot-thick alluvial layer, predominantly consisting of sand with discontinuous layers of clay and silt, that overlies a competent siltstone/claystone bedrock. This alluvial layer extends throughout the site with a saturated sand zone that is approximately 20 feet thick. Bedrock at the site is generally encountered at depths of 30 to 35 feet below ground surface (bgs) (northwest area is 50 feet bgs) and consists of a dark competent siltstone/claystone. A layer of weathered bedrock (of varying thickness up to 2 feet) is often present above the competent siltstone/claystone. The alluvium is mainly restricted to a basin that contains Best Slough and Dry Creek. A description of the regional hydrogeology and a detailed description of hydrogeology at Site 17 can be found in the *Basewide Hydrogeologic Characterization Report* (Law Environmental, Inc., 1998) and in Section 3.0 of the Final Site 17 RI Report (CH2M HILL, 2004a).

Hydrogeology

Beale AFB is located along the eastern margin of the Sacramento Basin Hydrologic Area as designated by the California Department of Water Resources (Law Environmental, Inc., 1998). Regional recharge sources include the Yuba, Bear, and Feather Rivers and mountain front recharge from the east.

Groundwater flow directions and gradients at Site 17 are primarily driven by the interaction between surface water and groundwater. Local sources of recharge to Site 17 include Best Slough, Dry Creek, Hutchinson Creek, Parks Lake, precipitation, and applied water. Throughout the year, groundwater flow is generally parallel to the streams, which is mainly to the south throughout the site. South and east of Best Slough, the horizontal groundwater gradient is approximately 0.003 foot per foot. This shallow gradient is primarily controlled by the surface water elevations in Best Slough and Dry Creek that bound this part of the site to the west and east, respectively.

Groundwater contours west of Best Slough also indicate a gradient toward the west (about 0.02 foot per foot) along the regional gradient that prevails at Beale AFB. According to groundwater modeling (HydroGeoLogic, Inc., 1999) and groundwater elevation measurements, the geologic materials below the ridge that lies to the west of the site are lower in permeability than the alluvial sediments along Best Slough and Dry Creek. Therefore, groundwater predominantly flows parallel to the streams and east of the ridge. The ridge gradually diminishes in size to the south, and, near the Base boundary, groundwater is believed to resume a westerly flow direction.

Nature and Extent of Contamination

The primary source area at Site 17 is near 11 shallow disposal trenches discovered at the site in 1985. The drums presumed to be the sources of contamination have been removed, and the slurry-wall IRA is currently controlling soil and groundwater contamination in this area. A secondary source area has been identified south of the slurry-wall-contained area. Primary contaminants at the site include chlorinated volatile organic compounds (VOC) and fuel-related compounds that originated in the source areas.

Trichloroethylene (TCE) is the most widespread chlorinated VOC at the site. Soil and soil vapor contamination at Site 17 are limited to the primary and secondary source areas. High concentrations of chlorinated VOCs and fuel-related compounds (total petroleum hydrocarbon [TPH]) have historically been detected in soil and soil vapor within the slurry wall. The sources of contamination have been removed, and the primary source area has been regraded and filled as part of the slurry-wall construction project. Recent soil and soil vapor sampling activities have focused on areas outside the wall because the slurry wall is preventing migration of contaminants outside the wall.

The soil and soil vapor near the secondary source area were investigated in 2002 and 2003. Passive soil vapor surveys were used to determine the locations of chlorinated VOCs in soil and groundwater with the highest concentration. The results of the passive soil vapor surveys defined the known extent of the secondary source area. Monitoring wells were constructed in 2002 and 2003, and located using the soil vapor survey results. The maximum concentration of TCE in soil vapor samples collected near the secondary source area is 4,680 parts per billion by volume (ppbv) in a sample collected at 1 foot bgs. TCE was also detected at 3,840 ppbv in a soil vapor sample collected from 10 feet bgs in the secondary source area, which suggests that soil vapor contamination extends to the water table.

Concentrations of TCE in groundwater at both the primary and secondary source areas suggest the presence of dense nonaqueous-phase liquids (DNAPL) in the subsurface. The TCE contamination has migrated south of the source area as evidenced by low concentrations detected near Parks Lake approximately 4,000 feet south of the source area. The most recent data demonstrate that the groundwater concentrations of TCE outside of the slurry wall exceed the maximum contaminant limit (MCL) of 5 micrograms per liter (µg/L) at 10 locations extending as far south as 1,000 feet south of the slurry wall. TCE has also been detected at concentrations well below the MCL in the surface water of Parks Lake, Dry Creek, and Best Slough. The most recent data set shows that TCE was only detected in two surface water samples at Parks Lake at concentrations of 0.2 and 0.09 µg/L.

Several other chlorinated VOCs and fuel-related compounds have impacted groundwater at Site 17. These other compounds also show higher concentrations near the source areas and decreasing concentrations with distance away from the sources.

The vertical distribution of contaminants generally encompass the entire saturated thickness of the alluvial water-bearing unit at Site 17. Contaminants have not impacted the saturated bedrock aquifer. This is supported by data collected from dual-completion wells that have been constructed at the site to collect information on the vertical distribution of contaminants.

Conceptual Site Model

A conceptual model is a three-dimensional representation of a site that conveys what is known or suspected about contamination sources, release mechanisms, and the transport and fate of those contaminants. The conceptual model provides the basis for understanding contaminant fate and transport issues and assessing potential remedial technologies at the site.

Groundwater flow at Site 17 is complex because of the presence of Best Slough and Dry Creek and the precipitation pattern throughout the year. The groundwater flow directions and gradients at Site 17 vary seasonally and are primarily driven by the interaction between surface water and groundwater. A pathway exists for groundwater containing TCE to discharge to Best Slough; however, because TCE is not persistent in surface water, it is rarely detected in samples from Best Slough.

Parks Lake is sustained by groundwater discharge. There is no surface water inlet to Parks Lake during times of normal stream flow. A shallow ditch could allow water from Best Slough to flow into Parks Lake; however, this ditch would not convey water except during flood flows. Thus, the surface elevation of Parks Lake is the same as the groundwater elevation near the lake. During the summer, evaporation from Parks Lake and evapotranspiration from the surrounding trees removes a substantial quantity of groundwater from the alluvial aquifer at Site 17. TCE is commonly found in surface water samples from Parks Lake because of the discharge of groundwater to the lake.

Since 1999, the groundwater contaminant plume, as indicated by the 5-µg/L contour line for TCE, appears to have decreased in size in the southern portion of the plume and increased in size to the west (Section 5.0 of the Site 17 RI contains a more detailed description of plume dynamics). Concentrations greater than 5 µg/L have recently been detected west of Best Slough in one monitoring well (17C001MW).

Contaminant migration from the primary source area has been controlled by the slurry wall installed in early 2001 as part of the IRA. A review of the water level and pumping data show that the slurry wall is performing as designed to hydraulically contain the primary source area. The secondary source area remains uncontrolled and continues to contribute VOCs to the dissolved plume.

Contaminants of Concern

In support of the Site 17 RI Report (CH2M HILL, 2004a) a human health risk assessment (HHRA), ecological risk assessment (EcoRA), and water resource assessment (WRA) were conducted to determine the relative risks posed by contaminants present at Site 17.

Table ES-1 contains the list of COCs that were determined to pose an unacceptable risk to human health or the environment. It is noted that there are currently no significant human health or ecological risks posed by contamination within Site 17. However, three groundwater contaminants were found to pose an unacceptable risk under the future scenario that drinking water wells were to be installed at Site 17. The hypothetical location of such wells was on the western boundary of Site 17 outside the 100-year floodplain. All other COCs were identified COCs on the basis of current or potential impacts to groundwater quality.

TABLE ES-1
Contaminants of Concern
Site 17 Feasibility Study, Beale Air Force Base, California

	Environmental Media Impacted		
COC	HHRA	EcoRA	WRA
1,1,1,2-TECA	NA	NA	Groundwater
1,1,2,2-TECA	Groundwater	NA	Subsurface soil and groundwater
1,1,2-TCA	NA	NA	Subsurface soil and groundwater
1,1-DCE	NA	NA	Groundwater
1,2-DCA	NA	NA	Groundwater
Carbon Tetrachloride	NA	NA	Groundwater
cis-1,2-DCE	NA	NA	Groundwater
Chloroform	NA	NA	Groundwater
Methylene Chloride	NA	NA	Groundwater
PCE	Groundwater	NA	Groundwater
trans-1,2-DCE	NA	NA	Subsurface soil and groundwater
TCE	Groundwater	NA	Subsurface soil, surface water, and groundwater
Vinyl Chloride	NA	NA	Groundwater
TPH-D	NA	NA	Groundwater
Manganese	NA	NA	Surface water, sediment, and groundwater

Notes:
DCE = dichloroethylene
DCA = dichloroethane
NA = not identified as a COC in the respective risk assessment and media
PCE = tetrachloroethylene
TCA = trichloroethane
TPH-D = total petroleum hydrocarbon as diesel

Remedial Action Objectives

Remedial Action Objectives (RAOs) are statements that define the extent to which sites require cleanup to protect human health and the environment. RAOs reflect the COCs, exposure routes and receptors, and acceptable contaminant concentrations (or range of acceptable contaminant concentrations) for each medium of concern at Site 17.

The general RAOs for Site 17 and other contaminated sites at Beale AFB include the following:

- Protect human health and the environment by reducing the risk of potential exposure to contaminants.
- Expedite cleanup and restoration of contaminated sites.
- Restore contaminated sites to the extent necessary to support existing and proposed land uses.
- Achieve compliance with ARARs.

The RAOs specific to the Site 17 FS are as follows:

- Continue to operate, maintain, and monitor the slurry-wall containment and pumping system to prevent the migration of groundwater contaminants away from the primary source area, thus minimizing further degradation of groundwater quality.
- Restore the quality of groundwater at the site, to the extent technically and economically feasible, such that groundwater is acceptable for designated beneficial uses. Beneficial uses include municipal and domestic water supply, agricultural supply, industrial service supply, and industrial process supply.
- Control and monitor the migration of groundwater contaminants to minimize expansion of the dissolved-phase plume.
- Protect human health by preventing exposure to contaminants in groundwater that would result in an increased lifetime cancer risk greater than 1×10^{-6} or a hazard index greater than 1 under a residential exposure scenario.
- Prevent the migration of contaminants from soil to groundwater at concentrations that would result in further degradation of groundwater quality or would cause noncompliance with ARARs.

Performance Criteria

To meet the RAOs established for the site, performance criteria are established to develop conceptual designs and cost estimates for the remedial alternatives. Because there are no remedial alternatives that can reliably remediate DNAPL within Areas A and B in a reasonable time, performance criteria are established separately for remedial alternatives that are ARAR-compliant versus noncompliant alternatives. Noncompliant alternatives (e.g., containment) will require an ARAR waiver on the basis of technical impracticability from an engineering perspective.

Performance Criteria for ARAR-Compliant Groundwater Alternatives

The performance criteria for ARAR-compliant groundwater alternatives evaluated in this FS, such as those evaluated for cleanup of the distal portion of the plume, are based on the state primary MCLs referenced in the California Code of Regulations, Title 22, Section 64444.

Remedial alternatives applied to the dissolved plume at Site 17 (Area C) will be designed to meet MCL concentrations in groundwater within a reasonable time.

A monitoring program capable of demonstrating conformance with the above performance criteria will be an element of each remedial alternative that is designed to restore groundwater to the MCLs.

These criteria apply to remedial alternatives for Area C and remedial alternative in Area B that do not include a containment component.

Performance Criteria for Containment Alternatives

Containment alternatives will not be designed to achieve the soil vapor or groundwater criteria described herein. Rather, the objective of containment alternatives is to be protective of human health and the environment, and protect water quality outside of the containment zone. The performance criteria for containment alternatives are as follows:

- No migration of contaminants outside of the containment zone, either horizontally or vertically that would:
  - Cause an increase in contaminant concentrations in soil, groundwater, or surface water outside the containment zone; or
  - Cause uncontrolled exposure to contaminants.

A monitoring program capable of demonstrating conformance with the above performance criteria will be an element of each remedial alternative that is designed to provide containment of contaminants.

Additionally, it is expected that containment alternatives will meet the criteria for attaining a waiver from groundwater cleanup ARARs on the basis of technical impracticability from an engineering perspective.

These criteria apply to all remedial alternatives evaluated for Area A and containment alternatives evaluated for Area B.

Performance Criteria for Soil Remedies

The existing soil vapor extraction (SVE) systems at other ERP sites within Beale AFB are operated to mitigate chlorinated VOC contamination in soil and soil vapor. Performance criteria for these systems were previously developed as part of the long-term operation and maintenance (LTO&M) for Beale AFB IRAs (CH2M HILL, 2004b). The LTO&M criteria were calculated to ensure that soil contamination does not contribute to the exceedance of MCL concentrations in groundwater. Subsequently, the California Regional Water Quality Control Board (RWQCB) has approved shutdown criteria for similar SVE systems installed at McClellan Air Force Base that provide decision factors for SVE system shutdown based on scientific, economic, and engineering judgement. Both of these existing SVE system criteria are used in this FS as performance criteria for soil remediation alternatives. For example, the soil vapor cleanup level for TCE is 350 ppbv, unless it is demonstrated that it is technically and economically infeasible to achieve such a level.

The soil performance criteria apply to active soil remediation alternatives.

Performance Criteria for Surface Water

TCE and manganese were identified in the Site 17 RI as COCs in surface water. The surface water performance criterion for TCE in surface water is 2.7 µg/L, which is derived from the California Toxics Rule (see Table 3-1). California Toxics Rule criteria are not applicable for manganese, and the background concentration of 93 µg/L (LAW, 1997) exceeds the secondary MCL of 50 µg/L. As explained in the Site 17 RI, elevated manganese concentrations in surface water are likely the result of natural geochemistry in combination with reducing conditions in sediments from naturally occurring organic debris. No active remediation of manganese in surface water is necessary to achieve RAOs and therefore, no performance criteria are established here.

According to surface water data collected over the past 2 years at Parks Lake, Dry Creek, and Best Slough, no surface water at Site 17 currently exceeds the preliminary cleanup goals for TCE of 2.7 µg/L. Thus, no active remediation of surface water is warranted.

Development of Remedial Alternatives

Remedial alternatives were developed by assembling remedial technologies and representative process options identified and screened in the technology screening process of the FS.

Remedial alternatives were developed on the basis of site-specific consideration primarily related to the nature of the COCs and their concentration and state (i.e., DNAPL versus dilute dissolved-phase concentrations), geology, and hydrogeologic conditions. Groundwater has been impacted in all three areas outlined below, whereas, only Area A and B soils have been impacted. Area A has an operating interim remedy that includes a containment slurry wall, groundwater capture and treatment system that uses air stripping and granular-activated carbon, and a phytoremediation system to extract groundwater. The IRA was designed to remediate COCs in soil and groundwater.

All of the remedial alternatives for Area A, except no action, include continued operation of the IRA. Appropriate land use controls are a component of each remedial alternative evaluated.

A summary of the remedial alternatives developed for each of the three target areas of Site 17 are summarized in Table ES-2.

TABLE ES-2
Description of Remedial Alternatives
Site 17 Feasibility Study, Beale Air Force Base, California

Groundwater

GW-A1 – No Action: No actions taken.

GW-A2 – Slurry Wall, Pump and Treat, and Phytoremediation (Existing IRA): This alternative is the current IRA that was implemented in 2000 to control discharges to groundwater from the source area solvent contamination at Site 17 and to prevent further surface water impacts to Best Slough.

GW-A3 – Injection with Emulsified Zero Valent Iron (EZVI): EZVI would be injected using several injection points into the zone known to contain DNAPL. A pilot test would be used to evaluate the success and benefit of the technology. According to the current understanding of DNAPL at Area A, DNAPL covers about 2 acres, and DNAPL mass is approximately 20 to 30 tons. Assuming a radius of influence of 30 feet, 100 injection points would be needed to deliver approximately 80 to 120 tons of EZVI into the DNAPL source area.

GW-A4 – Biostimulation/Bioaugmentation: The injection system required for biostimulation alternatives would be very similar to that of the Alternative GW-A3. A pilot test would be used to evaluate success and benefit of the technology. Assuming a 30-foot radius of influence for injection, 100 injection points would be needed to deliver approximately 100 to 150 tons of emulsified vegetable oil (EVO) into the DNAPL source area. It is estimated that the oil would be injected every 3 to 5 years (15 to 30 tons per injection) for approximately 15 to 20 years of operation.

GW-A5 – Zero Valent Iron (Ferox[SM] Process): Powdered ZVI would be injected under pressure using several injection points into the zone known to contain DNAPL. A total of 275 injection points would be used to pneumatically fracture the subsurface to 30 feet bgs and to inject a slurry of iron in the areas of greatest concentration in Area A. These injection points would deliver approximately 2,000 tons of ZVI to the DNAPL.

Area B

Groundwater

GW-B1 – No Action: No actions taken.

GW-B2 – Biostimulation/Bioaugmentation: A number of injection points (0.75 to 1.0 inch) would be used to deliver emulsified oil into the groundwater within Area B. Assuming a radius of influence of 30 feet, approximately 100 injection points would be needed to deliver approximately 5 to 7 tons of EVO every 3 to 5 years into the contaminated groundwater over a 15- to 20-year period.

GW-B3 – Groundwater Extraction and Treatment: Five new extraction wells would be constructed within Area B. A treatment plant designed to treat approximately 20 to 24 gallons per minute is required. The treatment plant would be designed to handle high concentrations and treat the groundwater via air stripping and granular-activated carbon. Treated water would be pumped to Parks Lake for discharge, resulting in little to no net loss of water levels in this important ecological area.

GW-B4 – Permeable Reactive Barrier: A PRB containing ZVI would be constructed on the south side of the existing slurry wall encompassing Area B. The constructed barrier would encompass an area of about 2 acres, have a perimeter approximately 700 to 900 feet long, and consist of both slurry wall and gates with ZVI/sand mixtures. At Area B, the PRB would be installed using conventional trenching to a depth of about 30 to 35 feet bgs. Groundwater passing through the PRB would be treated to meet cleanup goals required by ARARs.

GW-B5 – Slurry Wall, Pump and Treat, and Phytoremediation: This alternative is an extension of the Area A IRA and makes use of the existing treatment plant. The new slurry wall would encompass an area of about 2 acres in Area B. Some fill/soil material would be required to bring the land surface up to the existing IRA elevation. Alternative GW-B5 includes planting the area with perennial herbaceous vegetation and shrubs.

GW-B6 – Electrical Resistive Heating: The ERH electrodes conduct electrical current into the subsurface and are designed to input electrical energy at the targeted depth interval. This depth would be approximately 25 to 30 feet bgs at Area B. Each electrode is connected to one of the three electrical phases and would conduct current to every electrode that is adjacent to it. Resistance by the subsurface environment to this flow of electrical current uniformly heats the soil and groundwater between the electrodes and releases contaminants. Approximately 40 to 45 six-sided ERH cells would be needed to treat Area B.

GW-B7 – Excavation: An average excavation depth of 35 feet was assumed for the removal of contaminated soils and groundwater within Area B. This area extends 260 feet south of the slurry wall and 375 feet long, parallel to the slurry wall. Excavation would involve removing approximately 115, 000 to 125,000 cubic yards of soil. Temporary groundwater extraction would be required during excavation to dewater the zone of excavation. The extracted groundwater could be treated with the existing treatment system at Area A if possible.

Soil

S-1 – No Action: No actions taken.

S-2 – Soil Vapor Extraction: A total of five vertical SVE wells or two horizontal wells would be installed for remediation of TCE and PCE, and any potential volatile petroleum hydrocarbons in site soils. Offgas would be treated using granular-activated carbon.

S-3 – Phytoremediation: Herbaceous vegetation and water-tolerant shrubs would be planted over a 1-acre area of Area B.

Area C

Groundwater

GW-C1 – No Action: No actions taken.

GW-C2 – Monitored Natural Attenuation (MNA): Existing and two new monitoring wells would be used to evaluate MNA at the midpoint and the distal portions of the TCE plume in Area C. TCE time series plots from these wells would be used to evaluate the significance of MNA in the mid to distal portions of the plume and to show a trend in MNA evaluation parameters. Cleanup goals are ultimately achieved through natural attenuation processes.

GW-C3 – Biostimulation/Bioaugmentation (Biobarrier): The biobarrier would be approximately 1,000 feet long along the downgradient edge of the plume and contain a total of approximately 23 injection wells. The injection wells would be left in place to facilitate multiple injections of a long-term donor such as EVO. An alternative approach would be an active crossgradient recirculation biobarrier. This would consist of six extraction wells and fifteen injection wells. Groundwater passing through the barrier is treated to cleanup levels.

GW-C4 – Groundwater Extraction and Treatment: A total of nine new extraction wells would be constructed in Area C. A treatment plant designed to treat approximately 50 to 60 gallons per minute of extracted groundwater would be constructed. The treatment plant would be designed to handle low loading rates (average concentrations of chlorinated VOCs area less than 75 μg/L. To prevent dewatering of the surface water bodies, treated water would be pumped to Parks Lake for discharge resulting in little net loss in this area.

Comparison of Remedial Alternatives

Remedial alternatives developed and presented in Table ES-2 were evaluated for their performance against the seven CERCLA evaluation criteria and the results of the NEBA. Tables ES-3 through ES-6 provide a summary of the remedial alternative's performance. A letter ranking (A, B, or C) was assigned to each alternative and each criteria, with "A" indicating the best performance, "B" indicating moderate performance, and "C" denoting poor performance. The letter rankings are modified with "+" or "-" to denote more subtle variations in the alternative's ability to meet the criteria. Table ES-7 provides a summary of the estimated costs for each of the remedial alternatives.

Area B Soil Alternatives

When evaluated against the CERCLA criteria, all of the soil alternatives evaluated, including No Action, are generally equal in their overall performance. This is because soil remediation was evaluated primarily to determine if it would significantly enhance groundwater restoration, which is not a CERCLA evaluation criterion. Provided an appropriate remedial strategy for groundwater is selected for Area B, the decision to select an active soil remedy will likely be based on factors other than risk reduction and CERCLA criteria. Such factors include the overall cost of groundwater restoration, with or without a soil remedy component. If a containment remedy is selected for Area B, which is likely, based on the evaluation, then an active soil remedy will have little benefit.

The results of the NEBA support no action for soils because risks would remain unchanged under each of the active alternatives, and the costs of enhanced groundwater restoration provided by an active soil remedy exceed the benefits by an unreasonable amount.

Area A Groundwater

The Area A groundwater alternative with the best overall performance against the CERCLA evaluation criteria is continued operation of the existing interim remedy. Although the other alternatives evaluated did provide enhanced mass removal, they would not be able to restore groundwater to the quality required for beneficial uses (due to significant DNAPL) and did not provide significant risk reduction. The No Action Alternative is not an appropriate remedy for Area A because it does not meet threshold criteria for protection of human health or the environment and would not meet ARARs or qualify for an ARAR waiver.

The NEBA results also favor Alternative GW-A2. The enhanced mass removal provided by the other alternatives does not provide any risk reduction or an increase in human use or ecological services that would justify the significant costs that would be incurred.

Area B Groundwater

The two slurry-wall containment remedies evaluated for Area B (Alternatives GW-B4 and B5) provide the best overall performance against the CERCLA criteria. Because of the presence of DNAPL in Area B, treatment or removal alternatives are not as reliable for protecting downgradient groundwater from further degradation. If any DNAPL were to remain after treatment or removal, which is likely, based on the limitations of technology, residual risk to groundwater resources would continue to be unacceptable in Area B. Therefore, Alternatives GW-B2, GW-B6, and GW-B7 were judged to have lower overall performance than Alternatives GW-B4 and GW-B5. Although the pump and treat alternative (GW-B3) provides containment, its cost and uncertainty of complete capture of contaminants resulted in lower overall performance than the slurry-wall alternatives. The No Action Alternative is not an appropriate remedy for Area B because it does not meet threshold criteria for protection of human health or the environment and would not meet ARARs or qualify for an ARAR waiver.

As with Area A, the NEBA determined that the differences in human health or ecological risk reduction among Area B alternatives is insignificant. Alternatives GW-B4 and GW-B5 resulted in the greatest net benefit, with Alternative GW-B5 having the lowest ecological service loss, and Alternative GW-B4 having similar, but lower cost than Alternative GW-B5.

Area C Groundwater

As with Areas A and B, the No Action Alternative for Area C groundwater does not meet threshold criteria for protection of human health and the environment or compliance with ARARs. On an overall basis, the remaining alternatives evaluated met the CERCLA criteria equally well. Although MNA has the potential to have the best overall performance, additional data are necessary to conclude its effectiveness against the CERCLA criteria. Because of this uncertainty, MNA was ranked slightly lower than the more active alternatives with respect to protection of human health and the environment, short-term effectiveness, and reduction of toxicity and mobility. However, the low cost of MNA and its relatively high performance against other criteria make MNA as effective overall as the other treatment alternatives. If, based on additional data, MNA is determined to be effective in maintaining a nearly static or shrinking contaminant plume, the overall performance of MNA would exceed the performance of extraction and treatment and biobarrier remedies.

According to the NEBA, there would be no change in the human health or ecological risk profiles under all four remedial alternatives developed for groundwater in Area C. However, Alternative GW-C1 would not protect against potential future impacts to groundwater resources. All alternatives had very similar human-use service gains and ecological service loss, which suggests the lowest cost alternative results in the greatest net benefit. Because no action does not comply with ARARs, MNA is the best choice based on NEBA.

Next Steps

This FS provides information to the Air Force and other stakeholders necessary to select the most appropriate remedial action for Site 17. Beale AFB, with consideration of input from the Department of Toxic Substances Control, RWQCB, and other stakeholders, will select the preferred alternatives for Site 17 and document the selection in a Proposed Plan. The Proposed Plan will be subject to public review and comment. Following consideration of public comments, the final remedy for the site will be documented in a ROD. The final remedial design and remedial action for Site 17 will be performed in accordance with the requirements contained in the ROD.

TABLE ES-3
Soil Comparative Analysis Matrix – Area B (Secondary Source Area)
Site 17 Feasibility Study, Beale Air Force Base, California

		Threshold Criteria				Balancing Criteria			
Remedial Alternative	**Major Components**	**Protection of Health and the Environment**	**Compliance with ARARs**	**Long-term Effectiveness and Permanence**	**Reduction in Toxicity, Mobility, or Volume**	**Short-term Effectiveness**	**Implementability**	**NEBA Analysis**	**Estimated Net Present Value/ Total Cost ($)**
Alternative S-1 – No Action	None.	B – Current risks because of soil contamination are within acceptable ranges, assuming groundwater is addressed.	A – No ARARs are identified that require soil cleanup provided that risk levels remain acceptable and a groundwater remedy is implemented.	B – Natural attenuation would play some role in the long term, although it would not be documented.	C – Reduction of toxicity would occur. Mass and volume could occur naturally, but could not be evaluated because no monitoring is conducted.	B – No remedial action would occur, therefore, there are no additional impacts resulting from implementation of technologies. RAOs would not be achieved.	A – Alternative is implementable.	There would be no change in human health or ecological risk profiles. There would be no ecological services losses (note: there are no human-use services for soil).	A – $0. Refer to Table 6-7 for a summary of costs and Appendix D for a detailed cost breakdown.
Alternative S-2 – Soil Vapor Extraction	Vertical SVE wells would be installed and treated with GAC or air discharge.	A – Residual risk, although currently acceptable, would be reduced further by contaminant mass removal.	A – This alternative would comply with all chemical- and action-specific ARARs.	B – Alternative would be effective while groundwater table is low. Alternative would not be effective when water table is high (winter months).	B – Reduction of toxicity occurs though SVE and photodegradation.	B – Soil vapor extraction can be implemented within a one year time and is immediately effective once implemented.	B – Alternative can be implemented; siting well depth/screen will be a challenge because of water table fluctuations.	No change in risk profiles, but future exposure reduced at a loss of only 0.1 dSAYs (1 percent) of ecological services compared to no action.	B – $1.1 MM. Cost is moderate. Refer to Table 6-7 for a summary of costs and Appendix D for a detailed cost breakdown.
Alternative S-3 – Phytoremediation	Herbaceous vegetation is planted at the surface to degrade/extract VOCs.	A- – Residual risk, although currently acceptable, would be reduced further by contaminant mass removal.	A – Alternative would comply with all chemical- and action-specific ARARs.	B+ – Alternative can be effective for longer than SVE if herbaceous plants are used.	B+ – VOCs are treated to nonregulated ethene/ethane in the root zone or are vented to the atmosphere for photodegradation.	B – Alternative takes more time than SVE to be effective (6 months).	A- – Alternative is implementable; phytoremediation is used as part of the IRA.	No change in risk profiles, but future exposure reduced. Phytoremediation portion of this alternative provides an ecological services benefit of 5.6 dSAYs (34 percent increase in services over no action).	B – $1.2 MM. Refer to Table 6-7 for a summary of costs and Appendix D for a detailed cost breakdown.

Notes:
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MM = x $1 million

TABLE ES-4

Groundwater Comparative Analysis Matrix – Area A (Primary Source Area)

Site 17 Feasibility Study, Beale Air Force Base, California

		Threshold Criteria				Balancing Criteria			
Remedial Alternative	**Major Components**	**Protection of Health and the Environment**	**Compliance with ARARs**	**Long-term Effectiveness and Permanence**	**Reduction in Toxicity, Mobility, or Volume**	**Short-term Effectiveness**	**Implementability**	**NEBA Analysis**	**Estimated Net Present Value/ Total Cost ($)**
Alternative GW-A1 – No Action	None.	C – Criterion is not met. Contaminant would be allowed to migrate away from the contained area.	C – Alternative would not comply with ARARs requiring restoration of the beneficial uses of groundwater and prevention of further degradation of groundwater. Alternative would not fulfill groundwater monitoring requirements.	C – Any identified risk would not be diminished. Without operation of the IRA system, further impacts to groundwater and surface water are likely.	C – The IRA system would be shut down and no active treatment conducted. Reduction in mass or volume would only occur by natural degradation, but would not achieve RAOs.	C – No remedial action would occur, therefore, no additional impacts would result from implementation of technologies. RAOs would not be achieved.	A – Alternative is implementable.	No change would occur in human health or ecological risk profiles, but future exposure would not be reduced. There would be a $25,000 human-use services loss, but no ecological services losses.	A – $0. Refer to Table 6-7 for a summary of costs and Appendix D for a detailed cost breakdown.
Alternative GW-A2 – Slurry Wall, Pump and Treat, and Phytoremediation (Existing IRA)	A slurry wall encompassing 5 acres would be installed and keyed to bedrock at 35 feet bgs. Groundwater extraction and treatment would use GAC. Phytoremediation (trees) is used to help reduce the reliance on the pump and treat system.	A – Risks to human health and the environment are controlled with current containment/extraction system.	B – Alternative would not meet groundwater quality established by ARARs, but would meet criteria for an ARAR waiver based on TI.	B – Very effective because TCE DNAPL is contained and water levels are maintained within the slurry wall to provide an inward gradient.	B- – Reduction of toxicity occurs though extraction and removal of groundwater-bearing TCE. This will take time to make an impact on toxicity or mass and volume reduction. Other areas outside the slurry wall are protected.	A – This remedy is already in place and requires no construction activities.	A – Alternative is implementable and currently operating.	No change would occur in risk profiles, although future exposure would be is reduced. There would be a $25,000 human-use services loss, but no ecological services losses.	B+ – $4.3 MM. Refer to Table 6-7 for a summary of costs and Appendix D for a detailed cost breakdown.
Alternative GW-A3 – Injection with Emulsified Zero Valent Iron	A vegetable oil-ZVI is injected into the DNAPL zones to facilitate reductive dechlorination.	A – Risks to human health and the environment are controlled with current containment/extraction system. EZVI is used to enhance treatment of DNAPL.	B – Alternative would not meet groundwater quality established by ARARs, but would meet criteria for an ARAR waiver based on TI.	B+ – EZVI can treat free-phase TCE DNAPL effectively provided that enough iron can be distributed to the DNAPL source.	B+ – VOCs are treated to nonregulated ethene/ethane, thereby reducing toxicity, mobility, and mass of impacted groundwater through both abiotic and biotic reductive dechlorination. This will take time to be effective.	B – Alternative is an enhancement to the current IRA, thus containment system is in place.	A – Alternative is implementable with the use of several injection wells.	No change would occur in risk profiles, although future exposure would be reduced. There would be a $25,000 human-use services loss and 42.6 dSAY ecological services loss (26 percent reduction compared to no action).	C – $8.0 million. Refer to Table 6-7 for a summary of costs and Appendix D for a detailed cost breakdown.
Alternative GW-A4 – Biostimulation/Bioaugmentation	An in situ nutrient (edible carbon substrates) is added and possible microbial consortia additions are made to stimulate biological reduction of VOCs to ethene.	A – Risks to human health and the environment are controlled with current containment/extraction system. Enhancement of DNAPL treatment occurs via biologically enhanced reductive dechlorination.	B – Alternative would not meet groundwater quality established by ARARs, but would meet criteria for an ARAR waiver based on TI.	B+ – Alternative can be very effective provided biostimulation can be implemented effectively within target areas. Effective carbon substrate mixing is the greatest challenge.	B+ – Chlorinated VOCs and hydrocarbons are treated to nonregulated ethene/ethane, thereby reducing toxicity, mobility, and mass of impacted groundwater over the long term. In situ treatment would be an enhancement to extraction alone. However, given the mass of DNAPL, it would still take a great deal of time for significant mass reduction to occur.	B – Alternative is an enhancement to the current IRA, thus containment system is in place.	A – Alternative is implementable. New injection and possibly new extraction wells would be needed.	No change would occur in risk profiles, although future exposure would be reduced. There would be a $25,000 human-use services loss and 50.8 dSAY ecological services loss (30 percent reduction compared to no action).	C – $7.1 MM. Refer to Table 6-7 for a summary of costs and Appendix D for a detailed cost breakdown.
Alternative GW-A5 – Zero Valent Iron Ferox℠ Process	ZVI is injected into the DNAPL zone using pneumatic injection fracturing to provide space for the iron in the subsurface. A number of wells or boreholes are used to inject the ZVI.	A – Risks to human health and the environment are controlled with current containment/extraction system. ZVI would enhance the treatment of DNAPL via abiotic reductive dechlorination.	B – Alternative would not meet groundwater quality established by ARARs, but would meet criteria for an ARAR waiver based on TI.	B+ – Source-zone treatment could increase likelihood of achieving cleanup goals within intermediate cleanup time frame. Alternative has small potential to impact existing phytoremediation system.	A – Alternative has the potential to significantly reduce mass and toxicity and possibly volume of impacted aquifer. Groundwater extraction provides additional reduction in toxicity, mobility, and volume.	B – Alternative is an enhancement to the current IRA, thus containment system is in place.	B+ – Alternative can be implemented using several injection wells for injection of ZVI under pressure.	No change would occur in risk profiles, although future exposure would be reduced. There would be a $25,000 human-use services loss and 12.6 dSAY ecological services loss (8 percent reduction compared to no action).	C- – $11.8 MM. Refer to Table 6-7 for a summary of costs and Appendix D for a detailed cost breakdown.

Notes:

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MM = x $1 million

TABLE ES-5

Groundwater Comparative Analysis Matrix – Area B (Secondary Source Area)

Site 17 Feasibility Study, Beale Air Force Base, California

		Threshold Criteria				Balancing Criteria			
Remedial Alternative	**Major Components**	**Protection of Health and the Environment**	**Compliance with ARARs**	**Long-term Effectiveness and Permanence**	**Reduction in Toxicity, Mobility, or Volume**	**Short-term Effectiveness**	**Implementability**	**NEBA**	**Estimated Net Present Value/ Total Cost ($)**
Alternative GW-B1 – No Action	None	C – It is likely that RAOs would not be achieved. Contaminated groundwater would not be contained and could affect other groundwater resources.	C – Alternative would not comply with ARARS requiring restoration of the beneficial uses of groundwater and prevention of further degradation of high-quality groundwater. Alternative would not fulfill groundwater monitoring requirements.	C – Any identified future risk would not be diminished.	C – No treatment processes. Reduction in mass or volume would occur by natural degradation, but would not likely achieve RAOs.	C – No remedial action would occur; therefore, no additional impacts would result from implementation of technologies. RAOs would not be achieved.	A – Alternative is implementable.	No change would occur in human health or ecological risk profiles, but future exposure would not be reduced. There would be a $15,500 human-use services loss, but no ecological services losses.	A – $0. Refer to Table 6-7 for a summary of costs and Appendix D for a detailed cost breakdown.
Alternative GW-B2 – Biostimulation/Bioaugmentation	Alternative involves in situ carbon substrate addition and possible microbial consortia additions to stimulate biological reduction of VOCs to ethene.	C+ – Risks to groundwater resources would be reduced over time with active reductive dechlorination. This alternative would take time to be protective, and would not likely remove all DNAPL. Because containment in not a component of this remedy, continuing contaminant migration could occur	C+ – Groundwater cleanup levels would not be met in a reasonable time. Because containment is not a component of this remedy, continuing contaminant migration could occur.	C – Alternative can be very effective provided biostimulation can be implemented effectively within target areas. Effective carbon substrate mixing is the greatest challenge. Continuing contaminant migration can occur.	B+ – VOCs are treated to nonregulated ethene/ethane, thereby reducing toxicity, mobility, and mass of impacted groundwater	A- – After reducing conditions are established (normally 2 to 3 months), alternative is very effective over the short term.	A – Alternative is implementable. New injection and possibly new extraction wells would be needed.	No change in risk profiles, although future exposure is reduced; $9,000 human-use services loss (gain of $6,500 over no action) and 15 dSAY ecological services loss (35 percent reduction compared to no action).	B- – $5.2 MM. Refer to Table 6-7 for a summary of costs and Appendix D for a detailed cost breakdown.
Alternative GW-B3 – Groundwater Extraction and Treatment	New groundwater extraction wells would extract water at highest concentrations zones. Treatment of VOCs would occur via air stripping or possibly via engineered wetlands.	B+ – Risks to groundwater would be reduced over the long term through hydraulic containment and ex situ treatment. Significant time would be required to achieve concentrations in groundwater protective of human health and the environment without requiring land use controls or monitoring.	B+ – System designed to comply with all chemical- and action-specific ARARs downgradient of extraction system. Groundwater within capture zone would not meet cleanup levels in a reasonable time.	B- – Uncertainty exists on whether groundwater pump and treat would attain cleanup goals within a reasonable time frame. Long-term management would be required including regular maintenance or possible expansion of system	B – Plume could be contained using a properly designed system. Toxicity and volume of extracted groundwater would be reduced by aboveground treatment. Cleanup goals might not be achieved in areas of high concentrations, and the volume and toxicity of the groundwater would not be fully reduced.	B – Potential risks to the community, workers, and the environment during implementation of remedial actions would be mitigated outside capture area. Alternative provides significant time to achieve cleanup goals and associated RAOs.	B – Alternative is implementable with a well-established technology. Monitoring is currently being conducted as part of the BGMP. Offbase groundwater use restrictions would require coordination with property owners and state and local agencies.	No change in risk profiles, although future exposure is reduced; $12,000 human-use services loss (gain of $3,500 over no action) and 4.5 dSAY ecological services loss (10 percent reduction compared to no action).	C – $7.1 MM. Refer to Table 6-7 for a summary of costs and Appendix D for a detailed cost breakdown.
Alternative GW-B4 – Permeable Reactive Barrier	ZVI would treat VOCs in situ at highest concentration area downgradient of known DNAPL.	A – Risks to human health and the environment would be controlled downgradient of PRB.	B+ – Alternative would comply with all chemical- and action-specific ARARs in area downgradient of PRB. Would meet TI waiver criteria in Area B.	B – ZVI PRBs are a well-established technology and have been operating successfully for over 10 years in the field. This alternative would take time to reduce mass and volume in the secondary source area.	B – VOCs are treated to nonregulated ethene/ethane, thereby reducing toxicity, mobility, and mass of impacted groundwater provided that DNAPL or very high concentrations do not migrate into the PRB	A – PRBs installed in a UST would be effective at treating TCE immediately.	A – Implementable using conventional trenching equipment.	No change in risk profiles, although future exposure is reduced; $8,000 human-use services loss (gain of $7,500 over no action) and 5.8 dSAY ecological services loss (13 percent reduction compared to no action).	B – $4.2 MM. Refer to Table 6-7 for a summary of costs and Appendix D for a detailed cost breakdown.
Alternative GW-B5 – Slurry Wall, Pump and Treat, and Phytoremediation	Action is similar to Area 1 (primary source) using containment with a slurry wall keyed to bedrock and groundwater extraction/treatment for management/control of secondary DNAPL source	A – Risks to human health and the environment would be mitigated using well-established site-specific technologies. Groundwater extraction provides hydraulic control, preventing further migration.	B+ – Alternative would comply with all chemical- and action-specific ARARs for impacted groundwater.	B – Combination of technologies among the most suited to control and manage DNAPL. System could be maintained for the long term.	B- – Alternative has the potential to significantly reduce mass and toxicity and possibly volume of impacted aquifer. Groundwater extraction provides additional reduction in toxicity, mobility, and volume.	A – Containment is very effective over the short term. Over time, pump and treat and phytoremediation can reduce mass of TCE.	A – Alternative can and has been implemented at the site.	No change in risk profiles, although future exposure is reduced; $12,000 human-use services loss (gain of $3,500 over no action) and 1.5 dSAY ecological services loss (3 percent reduction compared to no action).	B – $4.7 MM. Refer to Table 6-7 for a summary of costs and Appendix D for a detailed cost breakdown.
Alternative GW-B6 – Electrical Resistive Heating	Electrodes would be installed into the zone containing DNAPL to heat the subsurface. TCE would be forced into the gaseous phase and captured using SVE	B – Risks to human health and the environment would be reduced over time. IT is unlikely that all DNAPL would be captured with ERH technology, leaving some residual source of free-phase TCE	B- – Alternative would not likely comply with all chemical-specific ARARs as some residual contamination would likely continue to migrate.	C – Very effective technology for removing DNAPL over the short term. Some residual DNAPL would likely remain.	A – Technology could reduce significant but not likely all mass of DNAPL in a short time. If this occurs, containment could be necessary	A – Alternative very effective over the short term. Significant mass reduction occurs in the first year of operation.	B+ – Implementable provided that subsurface conditions provide for even heating.	No change in risk profiles, although future exposure is reduced; $2,100 human-use services loss (gain of $13,400 over no action) and 9.6 dSAY ecological services loss (22 percent reduction compared to no action).	C- – $11.6 MM. Refer to Table 6-7 for a summary of costs and Appendix D for a detailed cost breakdown.
Alternative GW-B7 – Excavation	Soil containing free-phase DNAPL would be excavated. Excavated soil would be disposed of offsite	B – Risks to groundwater would be reduced or eliminated through excavation and offsite disposal. It is unlikely that all DNAPL would be captured with excavation at these depths and in bedrock.	B- – Excavation would not comply with all chemical- and action-specific ARARs if some DNAPL remains after excavation.	C – Uncertainty exists on whether excavation can remove DNAPL given the depths and subsurface bedrock environment.	A – Excavation has the potential to remove significant quantities and mass of free-phase TCE DNAPL, but not likely all of the DNAPL.	A – Alternative could be very effective in reducing mass and volume over the short term.	A – Alternative has been implemented and is one of the most common technologies for many near-surface COCs. Alternative not normally used to remove contaminants to 35 feet bgs	No change in risk profiles, although future exposure is reduced; $2,100 human-use services loss (gain of $13,400 over no action) and 11.1 dSAY ecological services loss (26 percent reduction compared to no action).	C- – $11.5 MM. Refer to Table 6-7 for a summary of costs and Appendix D for a detailed cost breakdown

Notes:

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MM = x $1 million

TABLE ES-6

Groundwater Comparative Analysis Matrix – Area C (Distal Plume Area)

Site 17 Feasibility Study, Beale Air Force Base, California

		Threshold Criteria				Balancing Criteria			
Remedial Alternative	**Major Components**	**Protection of Health and the Environment**	**Compliance with ARARs**	**Long-term Effectiveness and Permanence**	**Reduction in Toxicity, Mobility, or Volume**	**Short-term Effectiveness**	**Implementability**	**NEBA**	**Estimated Net Present Value/ Total Cost ($)**
Alternative GW-C1 – No Action	None.	C – It is likely that RAOs could not be achieved. Contaminated groundwater would not be contained and could affect other groundwater resources.	C – Alternative Would not comply with ARARs requiring restoration of the beneficial uses of groundwater and prevention of further degradation of high-quality groundwater. Alternative would not fulfill groundwater monitoring requirements.	C – Any identified risk would not be diminished.	C – Alternative has no treatment processes. Reduction in mass or volume would occur by natural degradation, but would not likely achieve RAOs.	C – No remedial action would occur; therefore, no additional impacts would result from implementation of technologies. RAOs would not be achieved.	A – Alternative is implementable.	No change would occur in human health or ecological risk profiles, but future exposure would not be reduced. There would be a $340,000 human-use services loss, but no ecological services losses.	A – $0. Refer to Table 6-7 for a summary of costs and Appendix D for a detailed cost breakdown.
Alternative GW-C2 – Monitored Natural Attenuation	Existing and new groundwater monitoring wells are monitored/sampled to evaluate the significance of natural attenuation at the site.	A- – Risks to human health and the environment would be reduced over the long-term. Significant time would be required to achieve concentrations in groundwater protective of human health and the environment without requiring land use controls or monitoring.	A- – System would be designed to comply with all chemical- and action-specific ARARs. There is some uncertainty on time frame to achieve groundwater ARARs and some risk of plume expansion.	B – MNA can be robust over the long term because no active management is required. With a remedy in place in Area B, this alternative could be very effective.	B – MNA processes provide reduction in toxicity, mobility, and volume. Additional data are needed to determine the effectiveness in Area C.	B – If MNA is robust, then the natural attenuation is already effective. Significant time would be required to achieve cleanup goals and associated RAOs.	A – Alternative is implementable. Monitoring is currently being conducted as part of the BGMP.	No change in risk profiles, although future exposure is reduced if combined with remedy at Areas A and B; $260,000 human-use services loss (gain of $80,000 over no action), but minimal ecological services loss (0.9 dSAY or less than 1 percent reduction compared to no action).	A – $2.8 MM. Refer to Table 6-7 for a summary of costs and Appendix D for a detailed cost breakdown.
Alternative GW-C3 – Biostimulation/Bioaugmentation (Biobarrier)	Alternative includes in situ nutrient (edible carbon substrates) addition and possible microbial consortia additions to stimulate biological reduction of VOCs to ethene.	A – Risks to human health and the environment would be reduced over the long term. Significant time would be required to achieve groundwater cleanup levels throughout Area C.	A – Alternative would be designed to comply with all chemical- and action-specific ARARs.	B – Alternative could be very effective provided biostimulation could be implemented and maintained over the long term. Effective carbon substrate mixing would be the greatest challenge.	B – VOCs are treated to nonregulated ethene/ethane, thereby reducing toxicity, mobility, and mass of impacted groundwater. The efficiency of treatment depends on the flow of contaminated groundwater across the treatment zone.	B+ – Once reducing conditions are established (normally 2 to 3 months), alternative is very effective over the short term.	A – Alternative is implementable. New injection and possibly new extraction wells would be needed.	No change in risk profiles, although future exposure is reduced; $260,000 human-use services loss (gain of $80,000 over no action), but minimal ecological services loss (10.5 dSAY or 1 percent reduction compared to no action).	B – $5.8 MM. Refer to Table 6-7 for a summary of costs and Appendix D for a detailed cost breakdown.
Alternative GW-C4 – Groundwater Extraction and Treatment	New groundwater extraction wells would be installed to extract water at distal end of plume and at highest concentrations zones. VOCs would be treated via air stripping or possibly via engineered wetlands.	A – Risks to human health and the environment would be reduced over the long term. Significant time would be required to achieve concentrations in groundwater protective of human health and the environment without requiring land use controls or monitoring.	A – System would be designed to comply with all chemical- and action-specific ARARs. Monitoring requirements would be fulfilled.	B – Pump and treat can be very effective over the long term through hydraulic containment and ex situ treatment.	B+ – Plume could be contained using a properly designed system. Toxicity and volume of extracted groundwater would be reduced by aboveground treatment. Some time would be required before RAOs could be met.	B+ – Potential risks to the community, workers, and the environment during implementation of remedial actions would be mitigated outside capture area. Significant time would be required to achieve cleanup goals and associated RAOs.	A – Alternative is implementable and uses a well-established technology. Monitoring is currently being conducted as part of the BGMP.	No change in risk profiles, although future exposure is reduced; $260,000 human-use services loss (gain of $80,000 over no action), but minimal ecological services loss (2.5 dSAY or less than 1 percent reduction compared to no action).	C – $7.0 MM. Refer to Table 6-7 for a summary of costs and Appendix D for a detailed cost breakdown.

Notes:

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MM = x $1 million

TABLE ES-7
Summary of Costs for Soil and Groundwater Alternatives
Site 17 Feasibility Study, Beale Air Force Base, California

Site or Area of Concern	Alternative ID	Alternative Name	Annual Costs	Estimated Years Operation	NPV Annual Costs	Direct Capital Costs	Indirect Capital Costs	Total NPV Costs
Area B Soil	S-1	No Action	$ -	-	**$ -**	$ -	$ -	**$ -**
	S-2	Soil Vapor Extraction	$ 102,206	7	**$ 624,945**	$ 242,438	$ 254,560	**$ 1,122,000**
	S-3	Phytoremediation	$ 43,697	50	**$ 1,024,941**	$ 70,929	$ 85,115	**$ 1,181,000**
Area A Groundwater	GW-A1	No Action	$ -	-	**$ -**	$ -	$ -	**$ -**
	GW-A2	Slurry Wall, Pump and Treat, and Phytoremediation (Existing IRA)	$ 181,381	50	**$ 4,254,392**	$ 33,120	$ 9,936	**$ 4,297,000**
	GW-A3	Injection with Emulsified Zero Valent Iron	$ 253,581	25	**$ 4,179,400**	$ 3,445,024	$ 380,564	**$ 8,005,000**
	GW-A4	Biostimulation/Bioaugmentation	$ 264,138	30	**$ 4,858,039**	$ 2,030,547	$ 254,023	**$ 7,143,000**
	GW-A5	Zero Valent Iron (Ferox[SM] Process)	$ 264,138	15	**$ 3,042,187**	$ 8,170,827	$ 609,579	**$ 11,823,000**
Area B Groundwater	GW-B1	No Action	$ -	-	**$ -**	$ -	$ -	**$ -**
	GW-B2	Biostimulation/Bioaugmentation	$ 174,728	25	**$ 2,879,790**	$ 1,736,573	$ 589,258	**$ 5,206,000**
	GW-B3	Groundwater Extraction and Treatment	$ 247,243	50	**$ 5,799,233**	$ 742,474	$ 593,979	**$ 7,136,000**
	GW-B4	Permeable Reactive Barrier	$ 113,926	50	**$ 2,672,194**	$ 841,785	$ 673,428	**$ 4,187,000**
	GW-B5	Slurry Wall, Pump and Treat, and Phytoremediation	$ 147,045	50	**$ 3,449,020**	$ 703,603	$ 562,882	**$ 4,716,000**
	GW-B6	Electrical Resistive Heating	$ 147,438	5	**$ 665,689**	$ 7,267,761	$ 3,706,558	**$ 11,640,000**
	GW-B7	Excavation	$ 106,866	5	**$ 482,505**	$ 10,143,342	$ 857,506	**$ 11,483,000**
Area C Groundwater	GW-C1	No Action	$ -	-	**$ -**	$ -	$ -	**$ -**
	GW-C2	Monitored Natural Attenuation	$ 118,086	50	**$ 2,769,789**	$ 32,918	$ 26,335	**$ 2,829,000**
	GW-C3	Biostimulation/Bioaugmentation (Biobarrier)	$ 177,508	50	**$ 4,163,557**	$ 1,399,330	$ 244,045	**$ 5,807,000**
	GW-C4	Groundwater Extraction and Treatment	$ 225,444	50	**$ 5,287,931**	$ 1,242,779	$ 534,395	**$ 7,065,000**

Notes:
Refer to Appendix D for a breakdown and itemized list of costs.
Cost estimates are accurate to within -30 to +50 percent.

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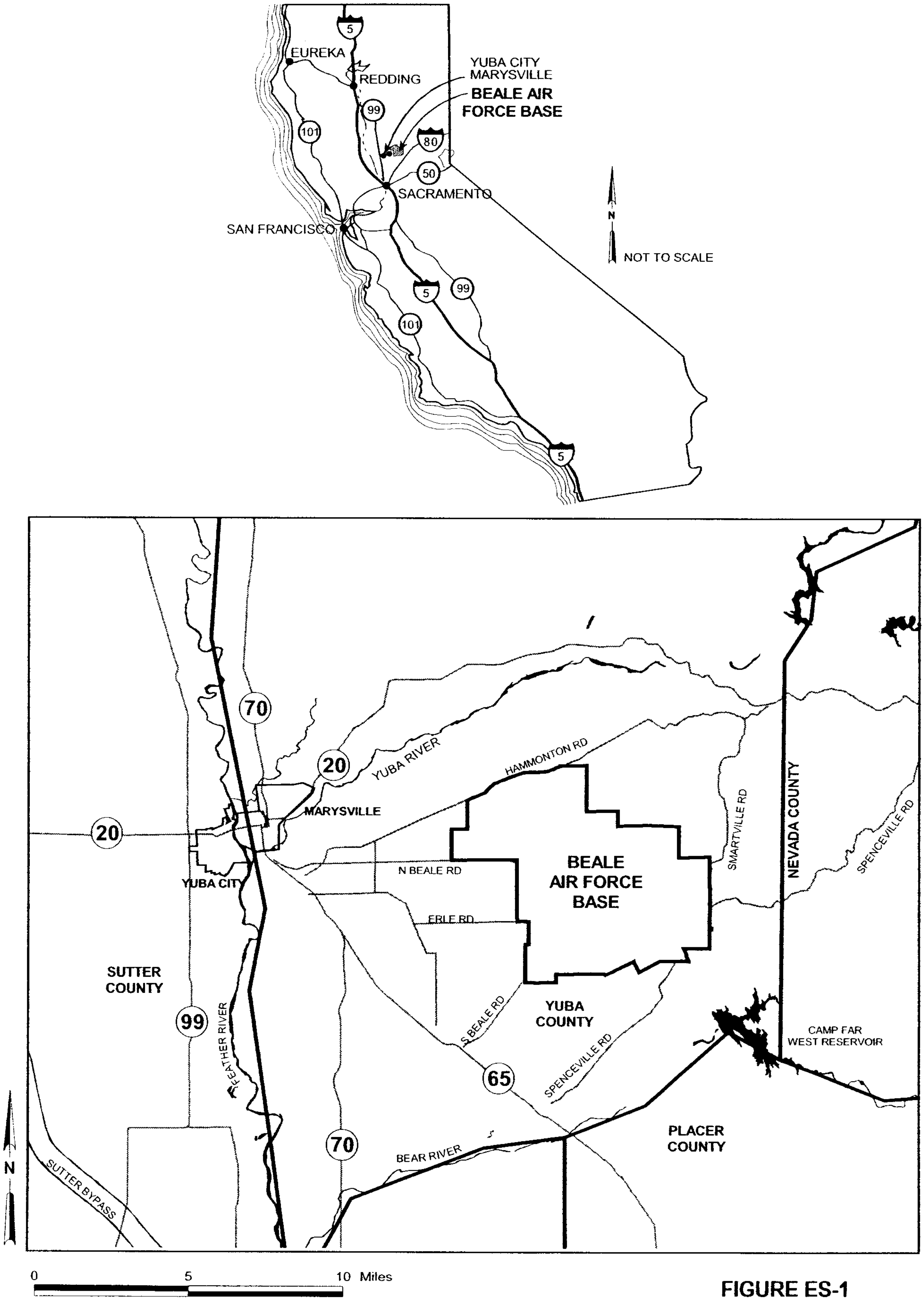

FIGURE ES-1
BEALE AIR FORCE BASE
LOCATION MAP
SITE 17 FEASIBILITY STUDY
BEALE AIR FORCE BASE, CALIFORNIA

CH2MHILL

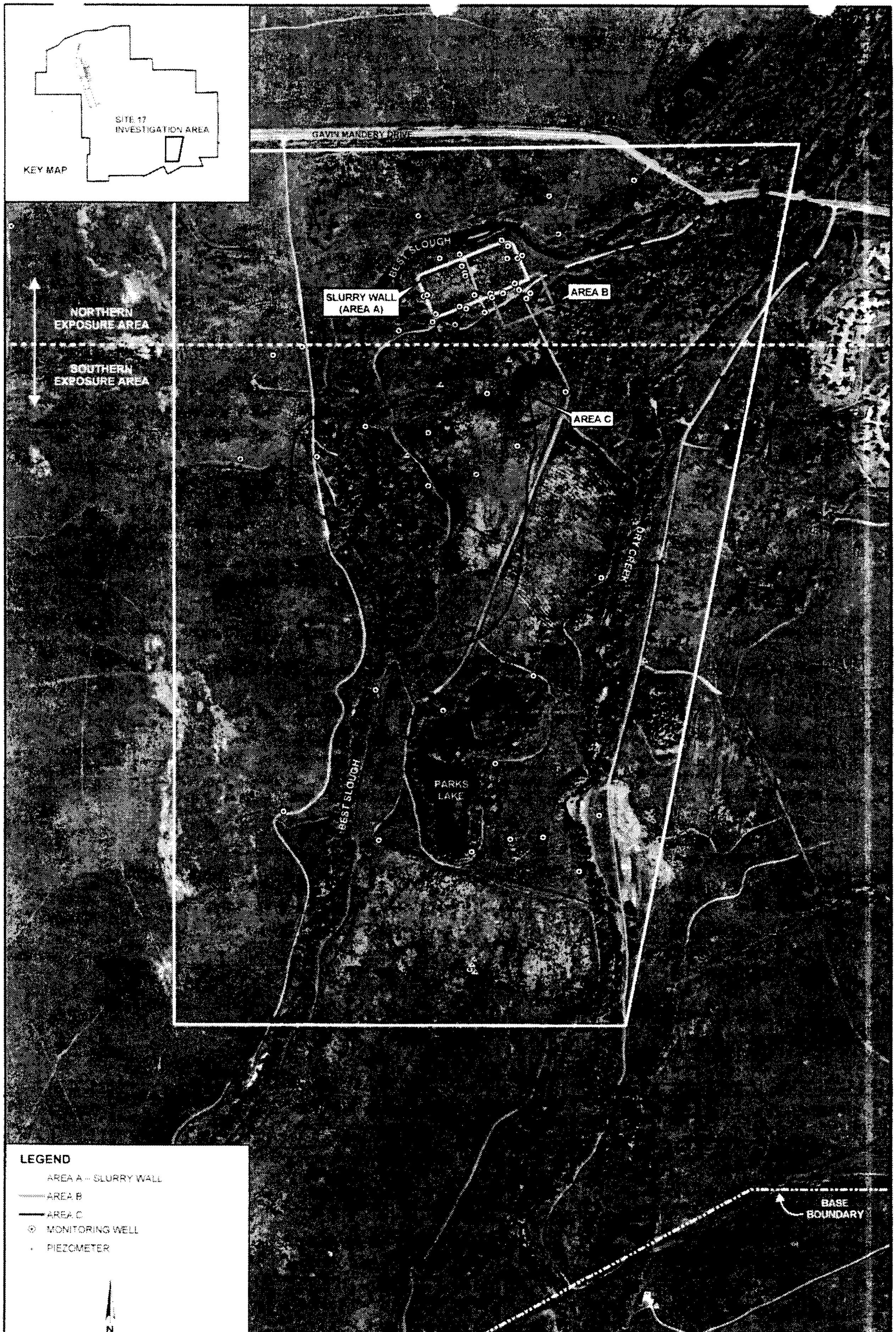

FIGURE ES-2
SITE 17 LOCATIONS AND FEATURES MAP
SITE 17 FEASIBILITY STUDY
BEALE AIR FORCE BASE, CALIFORNIA

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